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Using Quantile Mediation Analysis to Explore Relationships among Hydropower Energy Consumption, Economic Growth, and Carbon Dioxide Emissions in Taiwan

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Abstract: In this study, we employ the novel method of quantile mediation analysis to explore dynamic relationships among hydropower energy consumption, economic growth, and carbon dioxide emissions in Taiwan during the period between 1990 and 2020. The empirical results show that hydropower energy consumption only has a direct effect on reducing carbon dioxide emissions at a 0.2 distribution of carbon dioxide emissions. Moreover, results indicate that economic growth does not have a mediating effect between hydropower energy consumption and carbon dioxide emissions at any distribution of carbon dioxide emissions. Lastly, evidence produced by this study supports the existence of an environmental Kuznets curve in the context of Taiwan.

Keywords: carbon dioxide emissions; economic growth; hydropower energy consumption; environmental Kuznets curve; quantile mediation analysis

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1. Introduction

In 2015, 195 countries signed the Paris Agreement, agreeing to reduce the rise in global average temperature to within 2 degrees Celsius, largely through the reduction of carbon dioxide (CO_2) emissions. The exacerbating effects of CO_2 emissions on global warming are becoming increasingly obvious, causing uncontrolled temperature rises to occur earlier than anticipated, and leading to intensified climate change and more frequent occurrences of extreme weather events. A top priority for governments is thus to immediately and effectively reduce CO_2 emissions in order to mitigate the crisis that threatens the global economy and environment. The Intergovernmental Panel on Climate Change (IPCC) released a special report in 2018 to establish a global benchmark for action: global CO_2 emissions must reach net zero by 2050 at the latest [1]. The IPCC's most recent report stated that if governments manage to cut CO_2 emissions to reach net zero or even to lower CO_2 emissions substantially, we will see a deceleration in global warming and an improvement in air quality [2]. Therefore, efforts to reduce global CO_2 emissions and achieve zero emissions have become the focus of continuous attention for international organizations, governments, environmentalists, researchers, and scholars alike [3–7].

The most direct and effective way to reduce emissions of CO_2 caused by the burning of fossil fuels is to adopt alternative solutions through a shift to renewable energy, which do not produce harmful emissions on a significant scale. Muhammad and Khan [8] investigate the effect of renewable energy on CO_2 emissions by using data from 31 developed and 155 developing countries during the period between 1991 and 2018. The authors found that increased consumption of renewable energy plays a very important role in reducing CO_2 emissions. An energy transition strategy of using renewable energy to replace fossil fuel energy can contribute towards achieving the goal of net zero emissions and to the cause of global sustainable development at large, including several sustainable development goals.

Additionally, with the rapid growth of widespread renewable energy usage, many studies have demonstrated that renewable energy consumption has a positive effect on promoting economic development. For example, Bhattacharya et al. [9] studied the impact of renewable energy on economic growth in the top 38 countries in terms of renewable energy consumption from 1991 to 2012 and found that renewable energy contributed to economic growth in more than half of the countries. Zafar et al. [10] examined the member of Asia–Pacific Economic Cooperation (APEC) countries from 1990 to 2015, and results show that renewable energy has a positive impact on economic growth. Based on these results, the challenge of balancing the economy and the environment seems to be feasibly achievable.

Furthermore, many researchers have investigated the relationship between economic growth and CO_2 emissions [11–16]. Results of these studies show that the relationship between economic growth and CO_2 emissions varies with core factors such as regional economy, national development level, national income, and survey period. For example, Heidari et al. [15] investigated the relationship between real gross domestic product (GDP) and CO_2 emissions in five Association of Southeast Asian Nations countries between 1980 and 2008, and concluded that the assumption of a linear relationship between these two variables can be rejected. Therefore, the impact of economic growth on CO_2 emissions is not a simple linear relationship. Grossman and Krueger [17] proposed that economic growth affects environmental quality in three ways: scale effect, technology effect, and structural effect. A non-linear relationship can better reflect the relationship between economic growth and CO_2 emissions. This feature is perhaps best interpreted through the environmental Kuznets curve (EKC) hypothesis [18]. This hypothesis is the tendency of the variables between economic development and environmental pollution to show an inverted U-shaped curve, i.e., the impact of economic growth on environmental pollution is positive in the early stage of economic growth, then after economic growth reaches a certain high level, its impact gradually turns to a negative effect on environmental pollution.

Based on the above empirical literature which examines relationships between renewable energy and CO_2 emissions, between renewable energy and economic growth, or between economic growth and CO_2 emissions, there is a lack of empirical research that integrates the relationship among these three variables. Therefore, this study examines whether there is a direct and indirect relationship between renewable energy and CO_2 emission through economic growth in Taiwan. Moreover, we investigate whether the environmental Kuznets curve in Taiwan exists.

Previous econometric analyses on renewable energy have largely considered the variable of renewable energy as an aggregate variable. Few studies have carried out examinations by dividing each type of renewable energy in a disaggregated way. Moreover, the various types of renewable energy vary based on the geographical conditions and industrial development priorities of each country. Therefore, it is of interest to individually analyze different types of renewable energy on CO_2 emissions.

According to the definition of the United Nations Environment Programme, renewable energy refers to a theoretically inexhaustible natural resource that does not produce pollutants in the process. The most common examples are solar energy, wind energy, geothermal energy, hydropower, tidal energy, and biomass energy; all of them transform the energy of nature into energy and can be continuously regenerated depending on conditions specific to each type of renewable energy. Among renewable energy sources, hydropower is the world's earliest and most powerful system. It is currently the largest single renewable energy source, supplying 15.9% of global electricity in 2019 [19]. Hydropower is not only a clean and inexhaustible renewable energy, but also its development, utilization, renewal, and reuse process are part of a natural never-ending cycle. For these reasons, the main focus of this study is hydropower.

With abundant rainfall and generally steep terrain, Taiwan's natural conditions are very suitable for the development of hydropower, which led to it becoming the earliest renewable energy developed in the country. Since its large-scale implementation in 1905, hydropower has also been closely related to Taiwan's economic development. According

to Lee and Chang [20], who used the Multi-Criteria Decision-Making (MCDM) method to analyze Taiwan's renewable energy ranking, hydropower is the country's best renewable energy in terms of financing and technology and is the top priority for Taiwan in their quest to develop more renewable energy.

According to Taiwan's statistics from the Energy Bureau of the Ministry of Economic Affairs of Taiwan, hydropower energy consumption accounts for about 25% of Taiwan's renewable energy consumption sources, making it Taiwan's second largest source of re-newable energy consumption. Due to Taiwan's unstable climate and uneven distribution of rainfall in terms of time and space [21], hydropower energy consumption displays the highest hydropower consumption in Taiwan at 627,037 kl of oil equivalent (KLOE), and the lowest at 265,539 KLOE, with upward and downward trends from 1990 to 2020. Moreover, CO_2 emissions increased from 109.47 million tons (MMT) in 1990 to 259.21 MMT in 2007, with an average growth rate of about 8% per year, showing a clear upward trend. Then, CO_2 emissions displayed upward and downward trends between 247.53 and 257.43 MMT over the period from 2008 to 2020. In this study, we use data on Taiwan's hydropower consumption, economic growth, and CO_2 emissions from 1990 to 2020 and explore (1) whether there is a dynamic relationship between hydropower and CO_2 emissions, and (2) whether there is an indirect relationship between hydropower and CO_2 emissions through economic growth. In addition, we explore (3) whether the relationship between Taiwan's economic growth and CO_2 emissions shows an inverted U-shaped curve relationship in line with the EKC hypothesis. Moreover, we use a novel approach which integrates a quantile regression model combined with a mediating effect model analysis to examine the impact of hydropower energy consumption on CO_2 emissions in Taiwan from 1990 to 2020. This innovative approach can estimate the full range of dependent variables and is more robust in response to significant outliers. Especially when the disturbance term is non-normal, this quantile regression is more efficient.

The rest of the paper is organized as follows. In the Literature Review section, correlations between the variables in this study are introduced. The Research Methodology section provides an overview of the study's methodology and data analysis techniques. In the Results section, the results obtained by using quantile regression techniques are described. In the Discussion section, the findings are discussed with related empirical studies. Finally, in the Conclusions and Policy Recommendations section, interpretations, contributions, research limitations, and future research directions are discussed, as well as specific government policy recommendations.

2. Literature Review

According to many empirical studies, evidence supports the hypothesis that renewable energy is effective in improving environmental quality and reducing CO_2 emissions [22–33]. For example, Abbasi et al. [22] and Baek [23] examined the effect of renewable energy on CO_2 emissions in Thailand and the United States, respectively, and they indicated that renewable energy has a negative effect on CO_2 emissions in the short term; Haldar and Sethi [24] investigated the effect of renewable energy on CO_2 emissions in 39 developing countries, and showed that renewable energy can significantly reduce CO_2 emissions in the long run; Chen et al. [25], Cheng et al. [26], and Zoundi [27] reviewed the effect of renewable energy on CO_2 emissions using data from China, BRICS, and African countries, respectively. Results showed that the more renewable energy increases, the more CO_2 emissions decrease. Nguyen and Kakinak [33] differentiate high- and low-income countries to investigate the respective relationship between renewable energy and CO_2 emissions and found that renewable energy has a positive correlation with CO_2 emissions in low-income countries, but a negative correlation in high-income countries.

Regarding the relationship between renewable energy consumption and economic growth, many empirical studies have supported a positive link [34–43]. In particular, Yao et al. [34] indicated that a positive long-term relationship exists between renewable energy and economic growth in 17 major countries, including developed and developing

countries across six geo-economic regions around the world. Al-Mulali et al. [35] showed that a positive bilateral long-term relationship exists between renewable energy and GDP growth in 79% of the countries surveyed. Apergis and Payne [36], Apergis and Payne [37], and Lin and Moubarak [38] investigated 20 OECD countries, 6 Central American countries, and China; they also found that there is a positive two-way causal relationship between renewable energy and economic growth. Can and Korkmaz [41] analyzed the relationship between renewable energy and economic growth in Bulgaria between 1990 and 2016. The results demonstrated that renewable energy consumption and renewable electricity output are responsible for economic growth.

However, the previous literature study indicated that the relationship between renewable energy, economic development, and CO_2 emissions is mostly based on two variables. Therefore, in this study we use the concept of mediating variables [44] to combine the three correlations to explore whether renewable energy will further affect CO_2 emissions through economic development.

Many empirical studies support the EKC hypothesis proposed by Panayotou [18], which views the relationship between economic growth and CO_2 emissions as an inverted U-shaped curve [45–52]. For example, Ahmad et al. [45], Gao et al. [46], and Haseeb et al. [47] found out that the EKC hypothesis is supported in OECD economies, Mediterranean countries, and BRICS countries, respectively. Al-Mulali et al. [48] surveyed 170 countries, and found that the EKC hypothesis holds true in countries with high and moderate government efficiency; Bibi and Jamil [49], in a survey that distinguishes different geographic regions, found that except for sub-Saharan Africa, data from all other regions support the validity of the EKC hypothesis; Rana and Sharma [51] and Sarkodie [52] found evidence supporting the EKC hypothesis in their investigations of India and some African countries. Although the inverted U-curve shape of the EKC hypothesis may be adjusted for factors relevant to different geographic regions, development levels, government efficiency, and industries [45,49,53,54], this study believes that the analysis results combined with tracking data to describe the relationship between dynamic economic development and CO_2 emissions are suitable for describing the actual evolution process of the impact of economic development on the environment in the case of renewable energy use.

In academic research on the relationship among renewable energy, economic growth, and CO_2 emissions, most studies use aggregate renewable energy to explore the relationship between economic growth and CO_2 emissions [55–59]. Few studies use disaggregate renewable energy variables to analyze the relationship between economic growth and CO_2 emissions [60–65]. Anser et al. [60] and Li et al. [61] investigated eight South Asian countries and the South Asian Association for Regional Cooperation, respectively, and demonstrated that various types of renewable energy (hydropower, geothermal, and wind) have an impact on economic growth. Ummalla and Samal [62] empirically showed that China's hydropower, economic growth, and CO_2 emissions are all correlated in the long run. Xiaosan et al. [63] utilized time series models, including aggregated variables of renewable energy, and supported that there is a positive relationship between hydropower energy consumption on economic growth and CO_2 emissions in China. Sahoo and Sahoo [64] indicated that the effect of hydropower energy consumption on CO_2 emissions in India was not significant. Sharif et al. [65] investigated the effect of various renewable energy sources on CO_2 emissions in the United States and supported the existence of a negative link. Furthermore, various research results support the hypothesis that hydropower energy consumption contributes to economic development and reduces CO_2 emissions. Therefore, this study is different from previous studies in integrating three variables to establish a mediating effect model. The development of hydropower energy consumption will affect CO_2 emissions through economic development.

3. Research Methodology

This study refers to the research application of quantile regression in the field of en-vironmental economics [24,26,28,65–70]. For example, Hsu [28] used quantile regression

to explore the effect of economic growth as a mediation variable on aggregated renewable energy on CO_2 emissions in Taiwan. Although the results have not been supported, this method of combining quantile regression with mediation model analysis opens up another perspective to observe the relationship between renewable energy, economic growth, and CO_2 emissions. This pioneering application is worthy of continuous research in the field of environmental economics; Anwar et al. [70] used quantile regression combined with the EKC hypothesis to verify the existence of an environmental Kuznets inverted U-shaped curve relationship in the integration of ASEAN national panel data. They found the significance effect of the environmental Kuznets curve from the 30th to the 90th quantiles.

In this study, the mediation model analysis and EKC model analysis is carried out by using quantile regression techniques [66–68] with the purpose of examining the effect of hydropower energy consumption and economic growth on CO_2 emissions from 1990 to 2020 in Taiwan, whether through economic growth or not.

3.1. Quantile Regression

Koenker and Bassett [66] proposed quantile regression which was further developed by Koenker [67] and Koenker and Hallock [68]. This quantile approach is to estimate a conditional quantile function, which analyzes the distributions of the dependent variable affected by various independent variables and becomes an alternative to ordinary least squares (OLS) regression.

According to Koenker's quantile regression study [67], this technique in comparison to ordinary least squares (OLS) regression has some advantages. It estimates the full range of dependent variables and is more robust in response to significant outliers. Especially when the disturbance term is non-normal, this quantile regression is more efficient. The quantile regression is similar to least absolute deviation and its objective function is a weighted sum of absolute deviations. Therefore, the estimated coefficient vector is not sensitive to outlier observations on the dependent variable.

Equation (1) is the θ_{th} regression quantile minimization problem and has the solution as β_θ, which comes from the θ_{th} conditional quantile $Q_{y/x}(\theta) = x\beta_\theta$. This quantile regression estimates the marginal effect of an independent variable on the dependent variable under a specific conditional component.

$$\min_{\beta}[\theta \sum_{\{t:\, Y_t \geq X_t\beta\}} |y_t - x_t\beta| + (1-\theta) \sum_{\{t:\, Y_t < X_t\beta\}} |y_t - x_t\beta|] \tag{1}$$

3.2. Meditation Analysis

Baron and Kenny [44] proposed the most common approach for examining mediation effects. This mediation analysis has the following four steps which explain the relationship among the dependent variable, mediator variable, and independent variable:

The first step is to estimate the relationship between independent variable, the degree of hydropower energy consumption (HYDRO) and the dependent variable, carbon dioxide emissions per capita (CO_2) in Equation (2). If the coefficient of b_1 is significant, then we conclude that there is a direct relationship between HYDRO and CO_2.

$$CO_2 = b_0 + b_1 HYDRO + e_1 \tag{2}$$

The second step is to estimate the relationship between the independent variable HYDRO and to the mediator variable GROW which is measured by gross domestic product in Equation (3). If the coefficient of c_1 is significant, then we support the existence of the initial mediated effect.

$$GROW = c_0 + c_1 HYDRO + e_2 \tag{3}$$

The third step is to estimate relationship between the mediator variable GROW and the dependent variable CO_2 in Equation (4). If the coefficient of d_2 is significant., then we conclude that the final mediated effect exists.

$$CO_2 = d_0 + d_1 HYDRO + d_2 GROW + e_3 \quad (4)$$

As noted in the previous steps, the last step is to check if the independent variable HYDRO affects the dependent variable CO_2 after considering the mediator variable GROW in Equation (4). If the coefficient of d_1 is not significant, then we support that the complete mediation for GROW exists, that is, the relationship between HYDRO and CO_2 disappears when the mediated effect transmitted through GROW is estimated. However, if the coefficient of d_1 in Equation (4) is significant, but is smaller than the coefficient of b_1 in Equation (2), then we conclude that the partial mediation through GROW exists.

3.3. Quantile Meditation Analysis

In this study, we employ a novel quantile mediation analysis approach proposed by Hsu [69] that integrates quantile regression and meditation analysis. In other words, if we combine Equations (1)–(4), then we can obtain Equations (5)–(7). This innovative analysis can estimate all possible quantile parameters with high dependent variables or low dependent variables. Equations (5)–(7) describe the minimization of a weighted sum of the error for the quantile mediation regression:

$$\min_b [\theta \sum |CO_{2t} - b_0 - b_1 HYDRO_t| + (1-\theta) \sum |CO_{2t} - b_0 - b_1 HYDRO_t|] \quad (5)$$

$$\min_c [\theta \sum |GROW_t - c_0 - c_1 HYDRO_t| + (1-\theta) \sum |GROW_t - c_0 - c_1 HYDRO_t|] \quad (6)$$

$$\min_d [\theta \sum |CO_{2t} - d_0 - d_1 HYDRO_t - d_2 GROW_t| + (1-\theta) \sum |CO_{2t} - d_0 - d_1 HYDRO_t - d_2 GROW_t|] \quad (7)$$

According to Baron and Kenny [44], if the coefficient of b_1 (total effect) is significant in Equation (5), and the coefficient of c_1 in Equation (6) and the coefficient of d_2 in Equation (7) are also significant, then we can verify whether the coefficient of the d_1 coefficient is significant or not in Equation (7). If the coefficient of d_1 is significant but smaller than the coefficient of b_1, a partial mediating effect through GROW exists. Moreover, if the coefficient of d_1 is not significant, a complete mediating effect through GROW exists. However, when only either the coefficient of c_1 in Equation (6) or the coefficient of d_2 in Equation (7) is significant, then we use Sobel-Z test [71], that is, Equations (8) and (9) to verify the coefficient of c_1 and d_2 in Equation (7). If the *p*-value represented by the Z-value calculation result is less than 0.05 in Equation (9), the result indicates that a significant partial mediation effect through GROW exists [67].

$$SE_{b_1 d_2} = \sqrt{b_1{}^2 SE_{d_2}{}^2 + d_2{}^2 SE_{b_1}{}^2} \quad (8)$$

$$Z = \left| b_1 d_2 / SE_{b_1 d_2} \right| \quad (9)$$

3.4. Environmental Kuznets Curve

According to the classic EKC model of research [18,45–52], this study uses quantile regression technology, and examines whether a non-linear relationship between GROW and CO_2 exists, that is, if an EKC has an inverted U-shaped curve. To test whether the EKC relationship between GROW and CO_2 holds, we check the null hypothesis $\beta_2 \geq 0$ in Equation (6) at different quantiles θ of CO_2 emissions. If the *p*-value represented by the t value calculation result is less than 0.05 in Equation (6), the result indicates the existence of a significant EKC with an inverted U-shaped curve [72–74].

$$\min_{\beta}[\theta \sum\left|CO_{2t} - \beta_0 - \beta_1 GROW_t - \beta_2 GROW_t^2\right| + (1-\theta)\sum\left|CO_{2t} - \beta_0 - \beta_1 GROW_t - \beta_2 GROW_t^2\right|] \quad (10)$$

4. Results

In this study, we use annual Taiwan data during the period 1990–2020. The variables CO_2 (measures in millions of tons) and HYDRO (measures in kiloliters of oil equivalent) are from the Taiwan Energy Bureau. The variable GROW is from the *Taiwan Economic Journal*. These three variables take a logarithm.

We use the Augmented Dickey-Fuller (ADF) unit root tests to determine the order of integration for these three variables before estimating Equations (5) through (7). Table 1 shows the results of the quantile unit root test at the level. Results indicate that we reject the null hypothesis of a unit root at the 5% or 10% significance level for a three-level variable with stationary hypothesis.

Table 1. Results from the quantile unit root test.

	ADF t-Statistic (Level 1)							
Quantile	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**OLS**
HYDRO	−3.730 **	−3.163 **	−2.823 **	−2.271 **	−2.123 **	−1.898 *	−2.134 **	−4.177 **
CO2	−5.408 **	−4.843 **	−4.533 **	−3.844 **	−3.702 **	−3.334 **	−3.734 **	−5.548 **
GDP	−5.635 **	−5.633 **	−4.554 **	−5.109 **	−4.928 **	−4.645 **	−3.161 **	−3.673 **

* Indicates the t-Statistic is significant at the 10% level; ** Indicates the t-Statistic is significant at the 5% level.

Regarding the causal relationship between hydropower consumption, CO_2 emission and economic growth in Equations (5)–(7), the causal relationship test results are shown in Table 2. The signifier HYDRO $\neq$> CO_2 indicates that hydropower consumption does not affect CO_2 emissions. Likewise, HYDRO $\neq$> GROW means that hydroelectric energy consumption does not have the effect on economic growth.

Table 2. The quantile results from HYDRO to CO_2 and from HYDRO to GROW.

	HYDRO $\neq$> CO_2		**HYDRO $\neq$> GROW**	
Quantile	b_1	***p*-Value**	c_1	***p*-Value**
0.2	−0.531	0.037 *	−0.375	0.182
0.3	−0.447	0.121	−0.256	0.399
0.4	−0.345	0.247	−0.235	0.472
0.5	−0.090	0.757	−0.439	0.216
0.6	0.069	0.817	0.320	0.370
0.7	0.036	0.896	0.243	0.459
0.8	0.037	0.886	0.049	0.880
OLS	−0.273	0.137	−0.157	0.399

* Indicates the parameter is significant at the 5% level.

This study reached the following results. First, at 0.2 distribution of CO_2 emissions, HYDRO has a significant negative impact with CO_2, representing an increase in hydropower consumption and a reduction in CO_2 emissions, echoing the findings of Ummalla and Samal [62] and Xiaosan et al. [63]. However, HYDRO had no significant effect on GROW under any GROW distribution (see Table 2). Since c_1 is not significant in Equation (6) and d_2 is significant in Equation (7), we can use the Sobel-Z test to test Equations (6) and (7). The Sobel-Z value was 1.36 with a *p*-value of 0.087 (see Table 3); this indicates that there is no mediating effect between HYDRO and CO2. In other words, hydropower energy consumption did not affect CO_2 emissions through economic growth with 0.2 distribution of CO_2 emissions. It is shown that if the research is carried out on a single renewable energy source, empirical results may not have the same results as empirical research using

the total renewable energy due to heterogeneous development of individual renewable energy sources.

Table 3. The quantile results from HYDRO and GROW to CO_2.

	HYDRO $\neq$> CO_2		GROW $\neq$> CO_2		Sobel-Test	
Quantile	b_1	***p*-Value**	d_2	***p*-Value**	**|Z|**	***p*-Value**
0.2	−0.045	0.740	0.964	0.000 *	1.361	0.087

* Indicates the parameter or |Z| is significant at the 5% level.

Regarding the non-linear relationship between economic growth and CO_2 emissions, Table 4 shows that GROW and $GROW^2$ have significant effects on CO_2 emissions in each quantile, and that all $GROW^2$ coefficients are negative. The results show support for the EKC hypothesis as there is a non-linear inverted U-shaped curve relationship between economic growth and CO_2 emissions. This means that CO_2 emissions initially increase as economic growth increases, but when economic growth reaches a certain level, CO_2 emissions decrease as economic growth increases.

Table 4. The quantile results from GROW and $GROW^2$ to CO_2.

	GROW $\neq$> CO_2		$GROW^2$ $\neq$> CO_2	
Quantile	β_1	***p*-Value**	β_2	***p*-Value**
0.2	18.956	0.002 *	−1.301	0.002 *
0.3	19.286	0.004 *	−1.324	0.005 *
0.4	19.222	0.000 *	−1.321	0.000 *
0.5	20.048	0.000 *	−1.381	0.000 *
0.6	20.614	0.000 *	−1.421	0.000 *
0.7	20.505	0.000 *	−1.416	0.000 *
0.8	21.142	0.000 *	−1.460	0.000 *
OLS	18.483	0.000 *	−1.269	0.000 *

* Indicates the parameter is significant at the 5% level.

5. Discussion

This study extends Hsu's [28] quantile mediation regression to explore the dynamic relationships among Taiwan's hydropower energy consumption, economic growth, and CO_2 emissions. Results demonstrate that the hypothesis of the mediating effect of economic growth is reached, which is different from Hsu's [28] finding. Such a result may be related to the small sample. Moreover, this study provides a research direction for individual renewable energy that is different from the overall renewable energy. Although, our research only focused on hydropower in Taiwan, and failed to prove the mediation effect of economic growth. Future research can also continue to conduct research on different non-aggregated renewable energy. Through the comparison and analysis of various results, it will help provide a complete reference for Taiwan's renewable energy development strategy.

Echoing the advantages of the quantile regression expressed by Koenker [67], Koenker and Hallock [68] compared with the ordinary least squares (OLS) method, and found that the quantile regression can display all pictures of the impact of the explanatory variable to the explained variable at different quantile conditions of the explained variable. In our study, we found that hydropower energy consumption only has a significant impact on CO_2 emissions at the 0.2 quantile of CO_2 emissions, which is different from the regression results using the ordinary least squares (OLS) method. The results we found in the low quantile of CO_2 emissions are consistent with the empirical results of Sharif et al. [65] using quantile regression analysis of US hydropower on CO_2 emissions to support the negative impact effect.

In addition, we tested the EKC hypothesis with quantile regression for Taiwan. The results supported that the impact of economic growth on CO_2 emissions showed a nonlin-

ear inverted U-shaped curve relationship for the condition of different quantiles of CO_2 emissions. This is similar to the empirical results of relevant international research which supported the EKC hypothesis. For example, Yao [34] investigated France, the United Kingdom, Australia, Germany, Japan, Canada, Spain, and South Korea; Haseeb et al. [47] examined China, Russia, India, and South Africa; Saboori and Sulaimanm [75] investigated Singapore and Thailand. However, this study used quantile regression analysis to make full use of its advantages to analyze the overall picture and dynamic relationship of the impact of economic growth on CO_2 emissions.

6. Conclusions and Policy Recommendations

To obtain more reliable results and more information on the effects among hydropower energy consumption, economic growth, and CO_2 emissions, this study employs quantile mediation analysis to estimate the median and full range of the conditional distribution of the dependent variable. The results show that the effect of hydropower energy consumption on CO_2 emissions only occurs in the 0.2 distribution of CO_2 emissions, and no mediating effect of economic growth is found. In addition, we use quantile analysis to study the non-linear relationship between economic growth and CO_2 emissions, and the results show the presence of an EKC, and the distribution of CO_2 emissions from 0.2 to 0.8 all show an inverted U-shaped curve. With this in mind, this study has four main conclusions.

First, hydropower energy consumption can reduce CO_2 emissions when CO_2 emissions are low, but with economic growth and rising CO_2 emissions, hydropower energy consumption has failed to play a role in reducing CO_2 emissions. However, there is a non-linear relationship between economic growth and CO_2 emissions, which supports the EKC hypothesis that higher economic growth has the effect of reducing CO_2 emissions.

Second, we use data that breaks down renewable energy, namely hydropower, which is the most prominent renewable energy consumption in Taiwan because the technology is the most advanced and the cost is the lowest. Empirical results show that hydropower energy has a direct impact on CO_2 emissions. Therefore, there is still room for improvement in the development and utilization rate of Taiwan's hydropower energy consumption to provide more resources to promote economic growth to reach the net-zero decarbonization target. It is a very meaningful concept for energy substitution and environmental quality. Future research needs to continue to examine empirical results in different countries and regions. Moreover, we can examine different mediation effects, such as fiscal or monetary policy. This study is limited to the context of Taiwan, and rejects the hypothesis that it has a mediating effect on economic growth. Future research needs to continue to accumulate empirical results in different countries and regions to support.

Third, the quantile regression model is used to analyze and examine the relationship between economic development and CO_2 emissions showing a non-linear inverted U-shaped curve, which is helpful to support the effectiveness of Taiwan's decarbonization and net zero goals, as well as the cumulative academic scholarship regarding the EKC hypothesis. Moreover, we examine the quantile unit root test for each variable to support the quantile regression analysis results proposed by this study.

Finally, we employ a novel approach that combines the mediation effects model analysis and the EKC hypothesis model separately with quantile regression model analysis, which allows to estimate a full range of the conditional distribution of the explained variable, not just its conditional mean. In future studies, we can use this robust new method to continue to study the effect of various other renewable energy supplies on CO_2 emissions.

Based on the impact of Taiwan's hydropower on CO_2 emissions, it only exists in the lowest 0.2 quantile of CO_2 emissions. This means that hydropower energy consumption has no impact on CO_2 emissions when Taiwan's CO_2 emissions are high. Because Taiwan governments manage to cut CO_2 emissions to reach net zero or even to lower CO_2 emissions substantially and the effect of hydropower energy consumption exists when CO_2

emissions are low, it is still importance for Taiwan's government to develop and utilize hydropower energy.

Furthermore, due to the condition of insufficient hydropower energy, Taiwan's government should also develop different types of emerging renewable energy consumption sources, such as wind power and solar photovoltaics. For the effects of various types of renewable energy utilization, the method of this study can be used as a reference for in-spection and review.

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